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Nanotechnology in Space Exploration: Needs and Applications

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ABSTRACT

Nanotechnology is regarded world-wide as one of the key technologies of the 21st Century. Nanotechnological products and processes hold an enormous economic potential for the markets of the future. The production of ever smaller, faster and more efficient products with acceptable price-to-performance ratio has become for many industrial branches an increasingly important success factor in the international competition. Due to its interdisciplinary cross-section character, nanotechnology will affect broad application fields within the ranges of chemistry/ materials, medicine/life sciences, electronics/information technology, environmental and energy engineering, automotive manufacturing as well as optics/analytics and precision engineering in various ways. Also in space technology a high potential for nanotechnological applications is postulated. This paper throws light on some of the application of nanotechnology and nanomaterials in space exploration.

Keywords: Space technology, Application of Nanotechnology, Nnanomaterials, Space Exploration.

INTRODUCTION

Nanotechnology and nanoscience are multidisciplinary fields between biology, engineering, chemistry and physics of atoms or molecules of dimension less than 100 nm. Nanoparticles are larger than individual atom and molecules, but are smaller than bulk solid; hence they obey neither absolute quantum chemistry nor laws of classical physics and have properties that differ remarkably from those expected. Presently, the nanoscience and technology represents the most active discipline all around the world and is considered as the fastest growing technology revolution in the human history had ever seen. The interest in nanoparticles of these typical sizes is due to

the fact that the magnetic, optical and electronic behaviour of bulk materials can be modified when their size approaches the nanometer scale. Nanomaterials exhibit fundamentally unique properties with great potential application in electronics, computing, optics, biotechnology, medical imaging, medicine, drug delivery, structural materials, aerospace, space exploration, energy etc. In the last 20 years research has focused on understanding the origin of these new properties.

Various applications of nanotechnology in space appear to be feasible in a short to medium-term time horizon, which could lead to major improvements in the area of light weight and strong space structures, improved systems and components of energy production and storage, data processing and transmission, sensor technology as well as life support systems. Space flight could be utilized for research and development in the field of nanotechnology as well. Experiments in microgravity could supply relevant data regarding particle interactions or self-organization phenomena, which could be used for modelling and optimization of terrestrial process technologies in the range of nanotechnology. These examples represent potential space spin-offs for nanotechnology. Appropriate research and development projects have already been performed in particular by NASA, ESA and ISRO and other agencies since few years with substantial financial measures.

REQUIREMENTS FOR FUTURE SPACE SYSTEMS

An important criterion of nanotechnology applications in space is, to what extent these can make a contribution to the implementation of future requirements in space technologies and future missions in space travel[1].

1. Cost Reduction

Space Transportation: The cost reduction in space transportation can be done by reduction of mass and volume of spacecrafts and payload. At present, the costs amount to approx. 10,000 to 20,000 €/kg for transport into the earth‘s orbit. Therefore a high incentive results are needed for the miniaturization of spacecraft, which is possible in principle both on the level of components and modules as well as whole spacecrafts. Regarding the miniaturization of complete space systems at present, so called “Nano”-satellites (m< 10 kg) and even “Pico”- satellite (m< 1 kg) were examined, which possess as independent satellites among other things, their own propulsion and control systems. The development of such satellites makes a progressive miniaturization of all subsystems and the supply of efficient and lightweight power supply systems. The miniaturization of satellites however only makes sense if the payload can be miniaturizised without capability losses.

2. On-Board Autonomy

By increasing the on-board autonomy of spacecrafts, (e.g. autonomous attitude and orbit control, payload data processing, health monitoring of astronauts etc.) the operating costs for routine operationsand fault corrections could also be lowered. This could be achieved by nanotechnologically improved information

and communication technologies and sensor technology.

3. Increased Capabilities

Improved capabilities of future space systems are a further substantial objective both for scientific and commercial applications. In context with possible applications of micro-/nanotechnologies, innovation task forces were established by the NASA, ESA and other space agencies dealing with the following topics:

- Improved communication performance
- Instruments and sensors breakthroughs
- Innovative components and materials
- Intelligent space systems operation

4. Lowering of Mission Risks

The costs of payload development for space missions and of the space transportation are usually very high, so that a reduced mission risk is given a high priority. An important objective is therefore an increased reliability and durability of space components and systems. Here nanomaterials with improved mechanical and possibly intrinsic fault recognition and self healing properties as well as nanotechnologically improved sensors could supply a substantial contribution. A further possibility of lowering the risk of space missions is to increase the redundancy of space components and systems. For example, if the mission task would be distributed among a multiplicity of small satellites, the loss of one satellite would be far less serious than if only one satellite would be used, whereby its loss would usually cause the entire mission to fail. In this context miniaturized spacecrafts (nano-, pico-satellites, inspection probes, etc.) will play an important role in the future.

5. Innovative System Concepts

A further objective within the range of the space technologies is the realization of new system conceptions for different targeted applications. For example, the following space systems are under discussion, which partly possess visionary character:

- Constellations and swarms of miniaturized satellites and probes (“nano”, “pico”satellites, “flying chips” etc.)
- Stratospheric platforms (aerostats and gliders) for altitudes up to 45 km to complement satellites in some specific applications.
- Gossamer Spacecrafts (very large, light and self-unfoldable space systems with integrated subsystems e.g. thinfilm solar cells or phased-array-antennas) with applications in telescopes, mirrors, antennnas, starcovering-structures for the detection of planets outside the solar system, solar power plants in space (e.g. European Sail Tower or NASA Sun Tower)
- Inspection probes controlled either by the ground station or the spacecraft crew, for maintenance and monitoring the spacecraft (satellite, space stations etc.) and/or the exploration of space objects (planets, meteorites etc.)
- Space elevator (visionary conception) consisting of a cable, which has its center of gravity in geosynchronous orbit and is manufactured from ultra strength materials with extremely high strength-to-weight ratio, like for example carbon nanotubes.

POTENTIAL APPLICATIONS OF NANOTECHNOLOGY IN SPACE

Due to the outstanding functional characteristics of nanostructured materials, which are mainly based on a large surface-to-volume-ratio and on quantum effects, numerous potential applications arise in space.

Materials for space structures: A range of applications of nanomaterials lies in the construction of spacecrafts and space structures due their improved mechanical characteristics (higher firmness and stability and concurrently a lower density) compared with conventional materials. Nanomaterials could in particular contribute to the reduction of the lift-off masses of spacecrafts leading to substantial cost savings and also ensure safer and more flexible space missions.

Nanoparticle reinforced polymers: The mechanical properties of polymers can be improved by dispersion of nanoparticles into the polymer matrix. As polymer matrices for example epoxide, nylon, polyphenole or polyimide can be used. Due to its high mechanical firmness and resistance against heat and radiation, nanoparticle reinforced polymers have potential applications for various components in space, among other things as housings of solid-propellant rockets, as heat protection material in rocket nozzles, electrical isolations or fire protection applications. Also within the range of aviation, nanoparticle reinforced polymers are investigated intensively at present as lightweight structure materials for airplane bodies.

Carbon Nanotubes: Carbon nanotubes (CNT) with diameters of few nanometers as fullerene derivatives represent pure carbon compounds and occur in different modifications, e.g. single walled (SWCNT) or multi-walled (MWCNT). CNT possess unusual mechanical characteristics (on molecular level approx. 50 times stronger than steel and outstanding thermal and electrical conductivity). Due to their special properties, CNT possess numerous application in space, e.g. space structures, thermal control devices, sensor technology, electronics and biomedicine. In particular the huge potential for mass savings in space structures makes CNT very interesting for space applications.

Metal-Matrix-Composites: By reinforcement of metals with ceramic fibers, in particular silicium carbide, alumium oxide or aluminum nitride, their thermomechanical properties can be improved. Such metal matrix composites (MMC), e.g. SiC in aluminum alloys or TiN in Ti/Al alloys, due to their high heat resistance, firmness, thermal conductivity, controllable thermal expansion and low density, possess a high potential for aerospace applications and are examined at present, regarding the replacement of magnesium and aluminum in various structures of spacecrafts and aeroplanes. As it has been reported, the strength of MMC could be increased up to 25 % through nanostructuring and beyond that, superplasticity and a better resistance against material fatigue can be obtained in comparison to conventional MMC.

Nanocrystalline metals and alloys: The thermomechanical characteristics of metals and alloys can also be improved by

controlling the nano-/microstructure of the materials. Melting points and sintering temperatures can be reduced up to 30 %, if the material is made of nanopowders. Another advantage is the easy formability of the materials through superplasticity. Nano-crystalline aluminum alloys were developed for space applications as alternatives for titanium in components of liquid rocket engines, since they are lighter and less susceptible to embrittlement by hydrogen.

Nanostructured ceramics/ceramic nanopowders: Within ceramics a special focus lies on the production of controlled micro/ nano-structured grain sizes. An objective is the improvement of thermomechanical properties, fracture toughness and formability ("superplasticity") of this brittle material class. In addition, the sintering temperatures and the consolidation time of ceramic materials can be reduced by applying nanopowders, which saves not only money but also allows new manufacturing techniques like coprocessing of ceramics and metals. Both gas or liquid phase processes are used for the production of ceramic nanopowders.For non-oxidic powders (e.g. Si_3N_4, SiC, TiCN) gas phase processes is preferred and for oxidic powders (e.g. Al_2O_3, SiO_2) sol gel procedures is opted.

THERMAL PROTECTION

Due to the extreme conditions in space, thermal protection is an important topic. By improved thermal protection systems for re-usable spacecrafts the costs in space transportation could be lowered, and moreover, a higher mission flexibility and security in manned space travel could be obtained. Ceramic fiber composites can be used for high temperature components such as nozzles or combustion chambers of rocket engines or heat shields of reentry space systems.It can also have applications, such as:

- Substrate foils from oxide ceramics for reflector layers
- Formation of ceramic matrix from silicon-organic polymer precursors for complex structures
- Nanopowder (SiC, Al_2O_3) as a matrix component
- Nanostructured ceramic fibers
- Fiber coatings with nanoscale texture show, nanotechnology could be used favourably in the areas of thermal protection and hot structures for future reusable space transportation systems.

THERMAL CONTROL

Thermal control of space systems is another topic of high relevance. This deals with the protection of sensitive electronics against large variations in temperature. Nano-materials offer different approaches for an improved thermal monitoring of space travel systems. For example, nanostructured diamond-like carbon layers can improve thermal control systems of nanosatellites, since they possess approx. four times a higher thermal conductivity than copper[2]. Beyond that, diamond-like-carbon layers offer also corrosion protection, e.g. against atomic oxygen and are stable in a wide temperature range.

Energy generation and storage

Within the range of energy generation and storage nanomaterials,

nanolayers and nanomembranes will find applications as improved electrodes and electrolytes in condensers (supercaps), batteries (e.g. Li ion batteries) and fuel cells as well as photosensitive materials for high-efficient solar cells (e.g. quantum dot solar cells).

Solar cells

The efficiency of energy conversion of solar energy into electric current can be increased significantly by application of nanomaterials. Beyond that, anti-reflecting coatings for solar cells and collectors can increase the light conversion efficiency. While due to the mass restrictions in space transportation a maximum efficiency is aimed at, even if expensive manufacturing processes and materials are to be accepted, an appropriate durability of the collectors under space conditions must also be ensured (radiation and corrosion resistance). At present the most efficient solar cells for space applications are based on III/V-semiconductors such as GaAs and InP. Presently the most efficient solar cells for space applications have a conversion efficiency of approx. 30% [3]. Material systems for QD solar cells are III/V-semiconductors and other material combinations such as Si/Ge or Si/Be Te/Se. Potential advantages of these Si/Ge QD solar cells are:

- higher light absorption in particular in the infrared spectral region
- compatibility with standard silicon solar cell production
- increase of the photo current at higher temperatures
- improved radiation hardness compared with conventional solar cells

Batteries/Accumulators

High performance batteries are a substantial element of the power supply in space systems. The capacity and reversibility of rechargeable lithium batteries depend strongly on the microstructure of the electrodes. Nanostructured materials offer improvements regarding power density and durability by control of charge diffusion and the oxidation state on a nanoscale level. Nanostructured materials for electrodes e.g. carbon aerogels, CNT, vanadium oxide or $LiCoO_2$ particles are examined as cathode materials and nanostructured Sn/Sb oxides as anode materials. It has been reported that in lithium ion batteries a six fold increase in reversible charge capacity could be obtained by evenly distributed nanoparticles from cobalt, nickel and ferric oxides in the electrode material[4].

Life support: Nanotechnology has numerous potential applications in the range of life support system. As substantial tasks of life support systems in space travel, the following should be mentioned:

- O_2/ N_2 supply
- pressure monitoring
- ventilation
- heat absorption and rejection
- waste water treatment
- monitoring of water quality
- CO_2-removal
- hygienics
- air cleaning and filtration
- control of air quality and humidity

According to statements of NASA, very less applications of nanotechnology are registered within these ranges so far. As potential applications however, the following topics were mentioned[5].

- gas storage (high-efficient nanomaterials with high capacity-weight ratio primarily for nitrogen and oxygen storage, possibly as spin offs of hydrogen storage developments)
- waste water treatment (here at present activated charcoal filters and ion exchangers are used, potentials are seen for regenerative nanomembranes)
- Sensors (e.g. for monitoring filter processes within the range of water purification, for monitoring the air quality in space stations by means of electronic noses or for the detection of pathogenes)

Heat exchangers (heat exchanger so far are one of the largest and heaviest life support systems, therefore a high demand for weight reduction and miniaturization by means of nanostructured materials with more efficient heat exchange and transfer properties is existent)

International Scenario

NASA with m2mi have developed very small satellites, called nano-sats which weigh between 11 to 110lb, for the development of telecommunications and networking services in space. NASA says large groups of nano-satellites can be grouped in a constellation that will be placed in low Earth orbit to offer new telecommunications and networking systems and services[6]. NASA and m2mi are developing what they call fifth generation telecommunications and networking systems for TCP/IP-based networks and related services. The cooperative effort will combine NASA's expertise in nano-sensors, wireless networks and nanosatellite technologies with m2mi's unique capabilities in software technology, sensors, global system awareness, adaptive control and commercialization capabilities Fifth Generation technology, or 5G, incorporates VoIP, video, data, wireless, and an integrated machine-to- machine intelligence layer, for information exchange and use. Nano-satellites will be produced using low-cost, mass-production techniques. "The constellation will provide a robust, global, space-based, high-speed network for communication, data storage and Earth observations.

The Fast, Affordable, Science and Technology SATellite (FASTSAT) is 39.5 inches in diameter, not much larger than an exercise ball. It is hexagonally shaped and clocks in at a little less than 200 Lbs. It can carry a payload up to 110 Lbs.

NASA developed a volleyball-sized Miniature Autonomous Extravehicular Robotic Camera (Mini AERCam). This is designed to help astronauts and ground crews to see outside the spacecraft during a mission. During ground based testing, the device was able to work with the docking system that serves as an exterior home base for housing and refueling the nano-satellite. The Mini AERCam prototype is just 7.5 inches in diameter and weighs only 10 pounds.

National scenario

The ambitious project of IIT Kanpur with ISRO is the nano satellite named 'Jugnu'(3 Kg). A total of 62 students and

their heads did a magnificent job in bringing together the project. Jugnu was sanctioned two crore rupees but due to the indigenous technique the cost came down a lot. IIT and ISRO had signed a MoU to develop the nano satellite in 2008. This satellite, which is supposed to remain in air for one year, was launched with the help of Polar Satellite Launch Vehicle (PSLV). The data received from the satellite would then be used for research purposes in IIT Kanpur. Mainly, the satellite would provide information that would be used for flood, drought and disaster management. Prior to that, the agency had launched Anusat, another satellite developed by students.

A group of 35 students from the SRM University have been working on 'SRMSAT' since 2008 was recently launched. The satellite weighing just 10 kg and at a cost of Rs 1 crore will monitor gases from space."The satellite will monitor – mainly carbon dioxide in the atmosphere.

At present, five institutes IIT-Kanpur, IIT-Mumbai, Indian Institute of Space Technology, Sathyabhama Institute and Vellore Institute of Technology are building small satellites.

CONCLUSIONS

The increasing commercialization of manned and unmanned space travel and ever more ambitious missions for the scientific investigation of the solar system as well as, far space, require the development of more efficient, more economical and more resistant space technologies and systems in the future. Nanotechnology could contribute significantly to solutions and technological breakthroughs in this area. The low weights, Nano-Satellite have significant role to play in the cost reduction, experimentation, reduction in the development and testing time for the new technologies and will significantly change the satellite development activity in the future.

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